"KEEP'S TEST"

—FOR—

CAST-IRON.

112

Keep's Test for Cast-Iron.

A DESCRIPTION OF THE ROUTINE TO BE
PURSUED BY THOSE USING
THIS METHOD OF
TESTING.

W. J. KEEP.

DETROIT, MICHIGAN.
1893.

Introductory.

(*Editorial in American Machinist, Feb. 9, 1893.*)

Much has previously been written regarding this system of tests, and it has attracted a great deal of attention in Europe as well as in this country, but this is the first detailed and complete presentation of the matter in such form as to be taken up by practical foundrymen.

Both the main idea upon which the test is founded and the method of working out the problem are entirely original with Mr. Keep, who has devoted a great deal of study and hard work to them—study and work which he has enjoyed doing, however, for he is one of those enthusiastic students who, no matter what burdens may be laid upon them, find their recreation in the study of something connected with their work. In his position at the head of the largest stove manufacturing establishments in the world, Mr. Keep has had exceptional opportunities for knowing what is required, what is superfluous or impracticable, and what can be actually made to work in the hands of practical foundrymen.

With any material, such as wrought-iron, wrought-steel, etc., a small sample cut from a larger piece may be said to have very nearly, if not exactly the same properties and characteristics as the larger piece from which it is taken, and when tested, either chemically or physically, it is generally and properly taken to fairly represent the larger piece. With castings, however, the case is entirely different, as every practical man knows that different portions of the same casting may differ essentially from each other in strength and in other respects, while a small casting, though poured from the same ladle as a larger one, will in all probability give no direct indication of what the larger castings may be in important particulars. Knowing this, Mr. Keep has abandoned the attempt to establish a direct relation between the strength and other characteristics of castings and of test pieces, and has substituted therefor a system of testing which is entirely ***relative***, but by which every test made in any

foundry will be alike. The relation, then, which can be established between the results of these tests and the strength, etc., of castings, is simply that experience will show what an iron must stand by Keep's test in order to be suitable for certain purposes, and the record of any "Keep's Test" made anywhere or by any one will be as useful as any other by the same system, which cannot be said of other methods, even in testing wrought metals, much less when dealing with castings.

Of course, it is much to be desired that some plan might be adopted by which a test-piece casting would indicate exactly and directly the physical qualities of a casting of the same metal; but no method of doing this has been devised or seems likely to be. Mr. Keep's plan is, therefore, presented as the next best thing and the best practicable test.

Any one who has investigated the subject of testing at all must agree that some of the difficulties encountered in such work are very cleverly overcome by Mr. Keep, and the method by which he secures an autographic record, or, in other words, makes the machines themselves write a record of just what is being done during a test is a very valuable feature.

There is nothing in this matter which any intelligent foundryman cannot readily understand if he only wills to do it, and it is doubtful if any foundryman or other person responsible for the work of a foundry can now be considered well posted unless he does understand the principles involved in this system.

Keep's Test for Cast-Iron.

To ascertain whether cast-iron is suitable for a given purpose, its strength, shrinkage and chill must be determined.

The object of this paper is to advocate a standard test for cast-iron, that can be made expeditiously, and such that all tests may be compared with each other. The name of "Keep's Test" was proposed in the "Journal of the U. S. Association of Charcoal Iron Workers," in 1887. To give some idea of what has been revealed by its use, we refer to the papers mentioned in the foot-note at the bottom of this page.*

"Keep's Test" consists of a definite routine pursued in using special appliances, and the object is to make apparent to the eye the physical properties, and the influence of the chemical composition of the iron. The results are wholly *relative*, that is, greater or less than another test by the same method. When it is stated that an iron has a certain strength, shrinkage, etc., "Keep's Test," each detail of the test by which the result has been reached will be known, and, knowing the maximum and minimum results already reached by other users of this test, we know the value of an iron by the *relative* position that the results take between the extremes referred to.

The value of any record of test depends upon the operator adhering *absolutely* to the routine followed by others using this test. When the routine has become familiar, it will be found to be the natural way to proceed. After the castings of test bars have been made, an ordinary test can be completed in about half an hour.

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*Notes on "American Foundry Iron," South Staffordshire Institute of Iron and Steel Works Managers, 1888. "Physical Tests for Cast-iron," Journal of U. S. Association of Charcoal Iron Workers, 1887. "Influence of Aluminum upon Cast-iron," Trans. Am. Ass'n for the Advancement of Science, 1888. "Ferro Silicon, and the Economy of its Use," Transactions American Institute of Mining Engineers, vol. xvii, p. 258, 1888. "Silicon in Cast-iron," *ibid.*, vol. xvii, p. 683, 1889. "Aluminum in Cast-iron," *ibid.*, vol. xviii, p. 102, 1889. "Phosphorus in Cast-iron," *ibid.*, vol. xviii, p. 459, 1889. "Aluminum and Other Metals Compared," *ibid.*, vol. xviii, p. 798, 1890. "Aluminum in Wrought-iron and Steel Castings," *ibid.*, vol. xviii, p. 835, 1890. "Aluminum in Carbonized Iron," Journal of the Iron and Steel Institute (London), vol. i, 1890. "Manganese in Cast-iron," Trans. Am. Inst. M. E., vol. xx, p. 291, 1891. "Silicon in Foundry Mixtures," *The Iron Age*, June 9; the AMERICAN MACHINIST, June 16, 1892. We have in preparation papers on "Carbon in Cast-iron," "Sulphur in Cast-iron," "Chromium in Cast-iron," and "Keep's Test applied to Malleable Iron Castings."

The *Size* of Test Bars—The size and shape of the test bar is of the greatest importance. As all results are ***relative***, any size of bars might have been adopted; but we have decided upon a pair of bars cast together for gray iron, one of them $\frac{1}{2}\times\frac{1}{2}\times 12$ inches and the other $1\times\frac{1}{10}\times 12$ inches. We have found that the half-inch square bar will show the peculiarities of irons ranging from dark gray to white better than any other size, and will reveal the influence exerted by very slight changes in chemical composition, on account of sulphur in the fuel or from change of mixture.

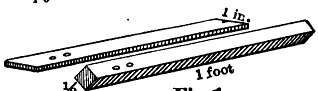


Fig.1

The thin bar ($1\times\frac{1}{10}\times 12$ inches) is more sensitive than the square bar. Any variation in the size or shape of a casting will change the grain of the iron, therefore no change must be made in the size of the bars or the method of gating.

The larger a casting the coarser the grain, and such coarseness will lessen the strength per unit of section. The founder, therefore, having ascertained the relative strength of an iron, or of a mixture of irons, by "Keep's Test," can, by a little experience, tell what it will be in a larger or in a smaller casting. Owing to the small size of these bars they can be made very nearly the exact size of the pattern, are convenient to handle, and all bars of a test can be preserved in a pigeon-hole $2\frac{1}{2}$ inches square and 12 inches deep. (Fig. 2.) It is often desirable to test a small quantity of iron, and with 12 pounds of metal six pairs of test bars can be made. For scientific work this is a great advantage.

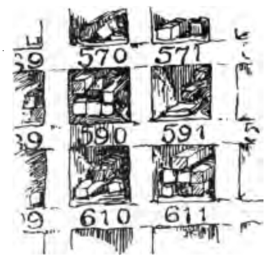


Fig. 2.

In this country a common form of test bar is $1\times 1\times 12$ inches; and in foreign countries a bar two inches high, one inch wide and two feet long is more common. Even the one-inch square bars cool so slowly that any slight variation in constitution is not likely to be apparent. The argument that the larger bars more nearly represent the metal of heavy castings is valid, but castings are never made of the dimensions of any test bar, and any variation vitiates the comparison.

It is, therefore, so far as this reason goes, as well to use one shape or size of test bar as another, and then reason out from experience what will be the effect of change of shape or size. A test of a single bar is of little value, as bars of the same size, and from the same ladle of iron, will show quite a variation. The more bars the better, and by the use of half-inch bars an average of four or six bars can easily be obtained.

Patterns.—These are made of bronze, and from one original set, to insure uniformity. They consist of an iron follow board (Fig.3), with gated patterns of a square and a flat bar. Accompanying these are four

pairs of yokes, as seen in Figs. 3, 7 and 15. These have parallel chilling surfaces 12⅛ inches apart, the ends of the bars running against these surfaces when poured. For those who wish more square bars, or use irons where the thin bar would always run white, a follow board (Fig. 4) containing patterns for two square bars and yokes to fit them is furnished. Four iron flasks, (Fig. 5), accompany the pattern, to insure the bars being duplicates of the patterns.

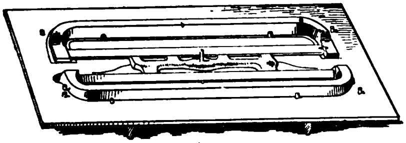


Fig. 3.

Molding.—The molds can be made by an ordinary bench molder in whom has been carefully impressed the necessity for always doing his work in exactly the same way, and who, once he has become thoroughly impressed with this idea, should be exclusively intrusted with this work, and made to appreciate its importance. He must use green sand of at least as good a grade as what is known as "No. 1 Albany," that has been tempered as for ordinary work, only rather dry, and which contains no sea coal.

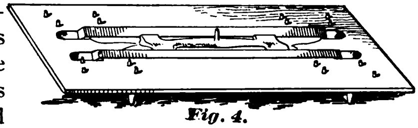


Fig. 4.

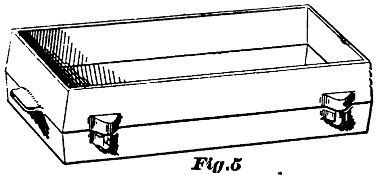


Fig. 5

Fig. 6 is a view of the molding bench in our testing room. The follow board is placed so that the square bar is towards the molder. He places No. 1 yokes upon it, after having moistened the chilling surfaces with a cloth on which is a little kerosone oil, to prevent rusting. A few casts without oil would ruin the surfaces, and the ends of the test bars would also be imperfect, but with oil the yokes will last for years, and the ends of the bars will be sharp and smooth. The pattern being placed in position between the yokes, the mold is made in the usual way, but the patterns must *never* be rapped. When the mold is rolled over and opened the patterns must be drawn so as to leave the mold the same size as

Fig. 6.

the pattern. No facing is used, and no slicking is done to the body of the mold. The mold of the square bar is now away from the molder (Fig. 7). With the sharp end of his slick he presses in the sand exactly the number of dots that he sees on the yokes. This number will *always* be on the farther side towards the *left* hand end of the mold of the square bar, and on the left end of the flat bar. If two square bars are in the mold the dots on the near bar *must* be on the side towards the molder, and at the ***right end.*** The reason for this location of the numbers is to insure the proper location of the bars in other parts of the test. Have all marks at one end of the bar, and leave the center of the bar smooth. Some sand will have worked in between the pattern and the chilling surface, this is removed with a slick. The parts of the flask are held together by ordinary bench molders' weights (Fig. 8). When the molds are all completed the number on each flask will indicate the number on the yokes in each mold. They are to be placed for pouring in the order of their numbers.

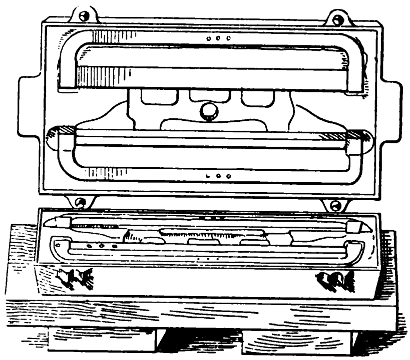


Fig. 7

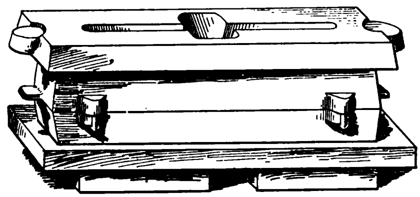


Fig. 8.

The iron should be caught each day at the *middle* of the heat, so as to represent the average iron.

That at the first part of the heat will be harder and weaker, from the influence of the fuel, and from the cupola being cold, while the iron at the end of the heat will be softer and stronger, from the furnace being hot. When through, wipe the sand and moisture from the yokes, and oil the chilling surfaces. Let the molder understand that each time before he places the yokes on the follow board, and after he is through with them, he is to oil the surfaces.

The average molder should be followed through the first set of molds step by step from start to finish, after which he will have no difficulty.

Rap the sand from the bars, break off the gates and tie the bars together, and attach a tag containing date and other necessary data. It is necessary to prepare this tag and give it to the molder, and particularly so if more than one cast is to be made in one day.

The molder will carry follow board, yokes and bars to the testing room.

Preparing the Bars.—Clean the sand from the bars, grind off the marks of the gates on an emery wheel, and grind the numbers nearly off, so as to leave flat bright spots. Hold the flat sides of the ends of the bars against the wheel, so as to make the edges of the ends sharp, but *do not, in any case,* let the bar slip so as to *touch the end surfaces of the bar to the wheel,* nor do any smoothing up on the sides of the bar with the wheel, except at the ends. Take a worn out file and rub each chilled surface of all bars, to remove the slight fin that has been turned by the wheel. The surface being chilled will not be injured by the file. With the same file rub the four sides at the center of the bar clean, but not bright. Leave the yokes and bars together over night, or until they are of the same temperature. Never open the package of more than one set of bars at one time, and, as soon as prepared, tie up and put on the tag.

Dimensions of Test Bars.—Take each square bar, (Fig. 9), and hold the number on top, and the gate marks at the bottom, and measure with a micrometer caliper the horizontal thickness of the bar. This is the *height* of the bar, and the other dimension is the *breadth* (see Fig. 10).

These measures are recorded for each test bar for future reference, and to see that the molder does not become careless. Each bar will vary sometimes from 5 to 10 one-thousandths of an inch, but this slight difference will not influence the result nearly as much as the variation in structure of each bar. They may, therefore, all be considered as half-inch bars.

Fig. 9.

Fig. 10

For convenience, cut a hole in the case containing the caliper, so that the measure of 500 may be left open.

Shrinkage.—The chief use of the yokes is to provide a means for measuring shrinkage.

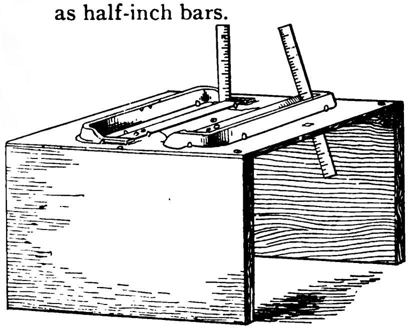


Fig. 11

In filling the molds, the iron runs against the chilling walls of the yokes (Figs. 7 and 15), so that the ends of the bars are perfectly parallel,

and when the metal is liquid, the bars are $12\frac{1}{8}$ inches long. As the metal solidifies and cools, the ends draw away from the chilling surfaces of the yokes.

The measuring table, (Fig. 11) is an exact counterpart of the follow board, with openings through it at both ends of each bar. The bars and yokes of the same number are placed upon this table so that they will lie exactly as they did in the mold.

The shrinkage is measured with a graduated steel wedge or gauge (Fig. 12). Each graduation marks one-thousandth of an inch in thickness of the gauge, and it measures from $\frac{100}{1000}$ at the thin end to $\frac{200}{1000}$ at the thick end, which will measure the shrinkage of all gray iron. A gauge is also made from $\frac{200}{1000}$ to $\frac{300}{1000}$ for white cast-iron and metals with a greater shrinkage than iron, and another from $\frac{50}{1000}$ to $\frac{100}{1000}$ for metals with shrinkage less than iron.

Fig. 12

Take No. 1 bars and yokes, the square bar towards you and the gate marks on the inside edge (see Figs. 11, 13 and 14). Shove the square bar to the right against the yoke and pass the measuring gauge down between the bar and the yoke, at the left end at the upper corner of the square bar, having the graduated edge away from you. Let the wedge go down as far as it will of its own weight, and read the graduation that corresponds with the upper edge of the bar; keep this reading in mind, withdraw the gauge, shove the bar to the left, enter the gauge on the right end and read the marking.

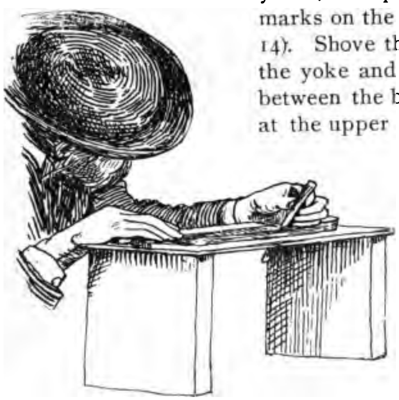


Fig. 13.

Record the average of the two readings 1 and 2 (Fig. 15), as the shrinkage of the cold edge of the bar. Now turn the gauge with its graduated edge towards you, and get the average of the two readings 3 and 4 of the inner or hot edge of the square bar and record it. Now carry the gauge in the same position over to the farther side of the thin bar and record the average 5 and 6 of the cold edge, then 7 and 8 of the hot edge of the thin bar. This record is shown in Figs. 20 and 30. Remove the No. 1 yokes and test bars, substitute No. 2

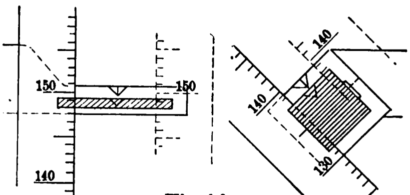


Fig. 14

and measure the shrinkage as before, and so on with all numbers. Foot up the average of each of the four columns. Take the mean of the averages of the hot and cold edges of the square bar for the ***shrinkage of the iron.*** A comparison of the shrinkage of the square and thin bar will show many peculiarities of the metal. Whenever we speak of the shrinkage of an iron "Keep's Test" we know that it is the average of at least four readings of as many ½-inch square bars one foot long.

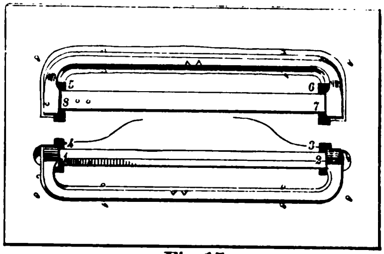


Fig. 15

The reason for always using the same yokes in which the bars were cast is that no two yokes are exactly alike, and there is a slight wear as their use continues. As all results are relative, a few are given. The lowest shrinkage noted for gray cast-iron was .105. The best shrinkage for stove castings is from .120 to .130 (silicon would be about 2.75). .150 to .175 is more usual in machine castings, showing silicon from 1.50 to 2.00 per cent. White iron has a shrinkage of from .200 to .260, according to silicon present. Wrought-iron melted and cast in a bar had a shrinkage of .292. Cast crucible steel with *C.* 1.52 was .255. A 16 per cent. ferro-silicon had a shrinkage of .315. The shrinkage of lead was .113, tin .053, antimony .068, zinc .148, copper .248, aluminum .166 to .191, alloys lead and tin equal parts (soft solder) .047, lead and antimony (common type metal) .064, common brass .190, bronze .177.

Strength.—In searching for a short name that shall indicate a stress applied transversely at the center of a test bar and gradually increased until the bar is fractured, and also to distinguish between this and a fracture caused by blows, each greater than the preceding, at the center of the bar, it has been difficult to find or invent a short word that will describe this and only this stress. We have decided to use the expression dead load for this application of stress. In previous papers we have used the word "weight" to represent this stress, and in consulting such papers this change in terms should be kept in mind.

Keep's Dead Load Testing Machine.—Fig. 16 is a single lever machine, in which, by moving a weight out on a beam *l*, a gradually increasing stress is applied to the center *i* of the test bar, which is held in flexible bearings *k k* exactly one foot apart. The beam is not kept floating, as in many machines, but as the stress increases it goes down with the center of the test bar. An autographic record is made of the behavior of the bar for every instant during the test.

The center *i* of the test bar is connected to an arm *a n*. The short end of this arm is attached to an adjustable flexible bearing *n*, and the

forward end *a* carries a pencil which bears on the diagram paper. The proportions of this are such that the motions of the center of the bar are magnified five times on the paper, and the record must be measured with a scale divided to twentieths of an inch, and read as hundredths.

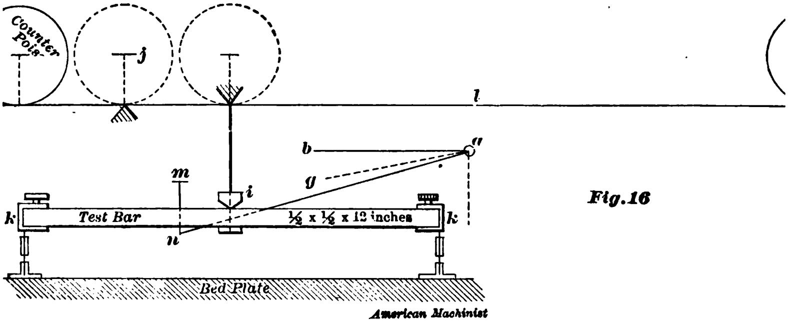


Fig. 16

The paper moves one-quarter as fast as the weight. The stress is read in pounds avoirdupois on the beam, and recorded on the diagram at the point of fracture. Do not trust to measuring the stress from the diagram.

The machine is practically frictionless, and the diagram is a correct representaton of the stress and strain.

Fig. 17 represents a diagram made by this machine. The base line *a b* is made by moving the paper horizontally while no stress is applied. If stress were applied, and the paper was not moved, the line *a c* would be described. If the test bar is a perfect spring, that is, if it is perfectly elastic, and the stress is increased, and the paper moved at a corresponding uniform rate, a straight diagonal *af* will be described.

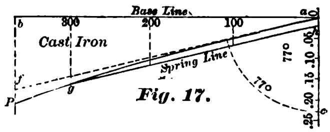


Fig. 17.

The distance from the base line *a b* to this spring line *af* at any point is the deflection at that point.

If the bar is of gray cast-iron, or of any metal not perfectly elastic, it will bend faster than a perfect spring, and will take a set for each increase of stress, and the diagram will be the line *a g*.

The distance between the spring line *af* at any point, and the line *a g*, will be the permanent set at that point. The distance from the base line to any point on the line *a g* will be the deflection, and will be made up of the elasticity measured above *af*, and set measured below *af*.

It is necessary at this point to give definitions of the terms which follow in italics. These were proposed in the paper "Aluminum and other Metals Compared," and were there treated more thoroughly than they can be treated here. The first definition separates elasticity from

the stress exerted to produce a change of shape, and from the work that a distorted body can perform while recovering its former shape. These definitions are proposed to meet the conditions as brought out by the use of "Keep's Test."

Elasticity is the property possessed by matter of regaining its original volume or shape after it has been distorted. Matter is *perfectly elastic* if it entirely regains its original volume or shape, and is *imperfectly elastic* if its recovery is only partial.

The diagram records *total deflection*, which is made up of *elastic deflection* above, and *set deflection* below the line *a f*.

Rigidity or ***stiffness*** is the ability of a material to withstand stress, and retain its original form. It is *perfect* when any stress which can be applied will not cause the material to change form.

The record or diagram of perfect rigidity would be the base line *a b*.

No rigidity would cause the form of a material to change without limit on the least application of stress, and the record would be the line *a c* perpendicular to *a b* at the zero point *a*. With any ordinary material the diagram of rigidity would be a line *a f* starting at the zero point, and lying between the lines *a b* and *a c*.

The angle that this line *a f* makes with *a c*, when all scales of the diagram are exactly the same as those here employed, indicates the *relative rigidity*. This angle is measured with a transparent protractor, the center being on the zero point, the base line *a b* passing through the 90° mark, and the graduated arc described with a 2½ inch radius. The no rigidity line *a c* is the base of the protractor, and we read the angle through which the spring line passes as the *rigidity angle*. The reason we must use a protractor of this exact size is because nearly all spring lines are curved, and we must select some one point on the curve.

When the test bar begins to take set, the diagram leaves the rigidity line, and the point where the lines separate marks the *limit of proportionality*, and indicates the stress at which proportionality ceases.

We will now resume the description of the machine. Fig. 18 is a perspective view: When the weight is at zero the counterpoise balances the beam. The weight and the diagram paper are propelled forward or backward by steel cords attached to the drum and crank at the rear of the machine. The traveling weight is 100 pounds, and the machine can exert a stress of 1,200 pounds. The arc at the forward end of the machine catches the beam when the test bar breaks.

To Test a Bar.—Run the weight to the left past the zero point, loosen the holder from the arc and raise the beam to the upper notch of the arc. Place the No. 1 square test bar in the supports, and tighten the end set screws. Always place the bar so that its number shall be at the right hand and on the side towards you. This brings the gate marks down and on the edge away from you. With a wedge provided for the purpose clamp the pencil arm to the center of the test bar. Slide

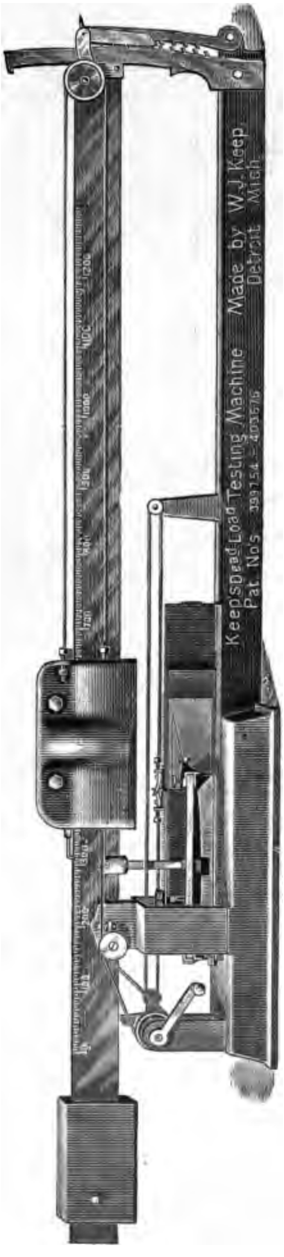


Fig. 18.

a strip of paper into the paper holder. Run the weight forward to the zero point, with the right hand raise the forward end of the beam out of the notch in the arc, and lower it until the pressure post bears on the bar. No stress is exerted on the test bar, and the pencil is therefore at its highest point.

With the right hand move the paper holder back and forth to draw a base line. Now attach the tightener to one of the pins of the paper holder, which push back slightly, to take up any slack in the cord. With a pencil make a mark over the point of the pencil *a* to represent the zero or starting point. See that the beam is free from the arc, and then run the weight out to the 300-pound mark.

Fig. 19, when the stress reaches 300 pounds step to the forward end of the beam, loosen the holder from the arc, raise the beam to the upper notch of the arc and close the holder. Return to the crank, with the right hand pull the pencil from the paper, and with the left run the weight back to zero. With the right hand lift the beam out of its notch and

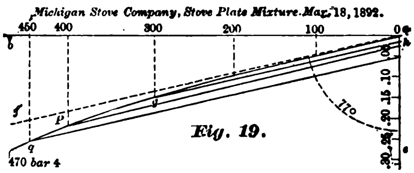


Fig. 19.

let it down until the pressure post rests on the test bar. Press the paper holder back to take up the slack of the cord and to bring the pencil under the zero of the diagram. The pencil will rest at *h*, and *a h* divided by 5, equals the set of the test bar for 300 pounds.

Run the weight forward again to the 300 pound mark, and a new diagram *h g* is drawn. The first and last diagram meet at *g*. We may release and apply the stress from 0 to 300 as many times as we choose,

and we find that the pencil always follows the line *h g*. Thus, although the test bar took set for every pound that the stress was increased up to 300 pounds during the first application, the bar has become a perfect spring and its nature has changed for all stresses less than 300. But the instant the stress exceeds 300 pounds the original character of the bar reappears, and the diagram beyond 300 is a continuation of the original diagram, and the upper line or diagram, taken as a whole, is exactly the same as it would have been if the stress had been continuously increased and had not been relieved at 300 pounds. After passing the 300-pound mark run carefully, watching the divisions on the beam so as to catch the reading at the breaking point. If the stress reaches 400 it is well to repeat the spring line. It is not often that we can catch a spring line for 450. All spring lines from the same bar are parallel.

The spring line from a tempered steel bar will be a straight line, but the spring lines from cast-iron and similar metals which take set are slightly curved lines.

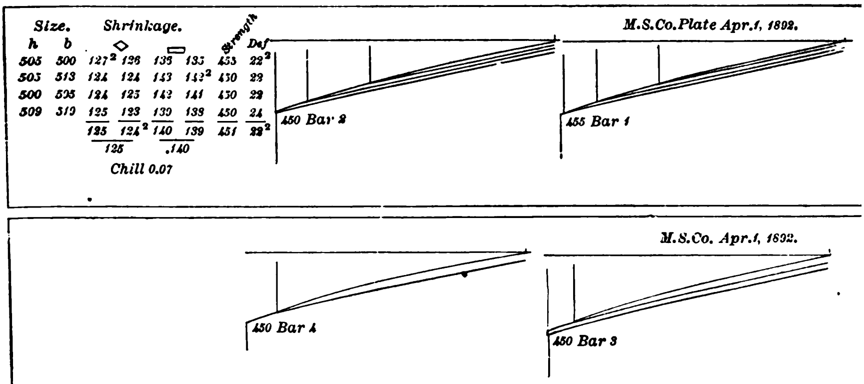


Fig. 20

American Machinist

When the first bar breaks take the paper out and record the breaking weight, as read on the beam, at the end of the diagram; also record the number of the bar, the date of cast, and any other condition attending the test, or, what is better, put the diagrams on the same paper on which size and shrinkage have been recorded (see Fig. 20).

When this record has been made raise the pencil from the paper, run the weight to the extreme left, and step forward and raise the beam to the top.

Raise the pencil to the highest point, loosen the wedge and end binding screws, and take out the broken pieces of the bar.

With the hand break the No. 1 thin bar and put the ends, containing the number, of both square and thin bar in a paper or pigeon-hole marked with the number and date of the test. Break the remaining bars in the

same way. It is well to make two or three diagrams on one side of the paper, and the rest on the other side, and if the rest of the record is on the same paper it is in a convenient form for preservation. In a foundry running on a uniform grade of work a test once a week is often enough, in which case the year's tests would be represented by 52 strips glued together at one end.

Fig. 20 represents the two sides of one of these record sheets greatly reduced in size, the actual length being 14 inches.

Referring again to the diagram, Fig. 19, a template may be made of the longest spring line, and it can be prolonged if necessary. This template can be placed parallel to the spring line, and with the zero point tangent with the first diagram at its zero point, a new spring line *a f* can be drawn. This divides all deflections into elastic deflection and set deflection, and all perpendicular distances between *a f* and *a g* are permanent sets. The angle of rigidity may be taken from this spring line *a f*. Note again that all results are ***relative***, and never reduce results to so much per square inch cross-section, for the reason that practice shows that the internal structure of a bar has so much more to do with the strength than the slight variation in size, that a comparison of the sizes of the bars with strength does not show that this small variation exerts any material influence on the results.*

We always record the actual strength of each of our standard bars. If an iron has a strength of 451 pounds "Keep's Test," it means that 451 is the average of, at least, four bars broken by the dead load machine.

The difficulty with making comparisons with records of other machines, is that they apply stress by means of a screw at the center of the bar, and then weigh the stress they have applied. This is not a gradual increase, and the bar often breaks during the application of stress and before the amount of stress is ascertained. In Keep's Test the bearings are always one foot apart, and the greatest accuracy is attained.

No oil should be used on these testing machines, as the dust from the bars will thicken the oil. If any part runs stiff clean out the dust. It may sometimes be best to use a little flour of emery to make a part work smoothly, or apply plumbago.

The greatest strength for any number of single bars yet recorded in our stove plate castings is 470, though we found one bar which broke at 500 pounds. The largest average for a set of 4 bars was 451 pounds. A

*The formula, that the strength varies directly as the square of the height of the test bar, directly as the breadth, and inversely as the length, may be correct for bars where the structure is the same in each, but from the fact that the grain varies with the size of a cast-iron test bar the formula cannot give correct results in calculating the strength of a large bar from the ascertained strength of a small bar, or *vice versa*. We may, however, approximate the strength of a bar one inch square and one foot long by multiplying our results by eight; if one inch square and two feet long multiply by four, or the strength of a bar two inches high, one inch wide and two feet long, by multiplying our results by 16.

bar from the ordinary mixture of Henry R. Worthington used for hydraulic machinery broke at 475 pounds. William Deering & Co., report a test bar from their cupola iron breaking at 488 pounds "Keep's Test." Above 350 pounds is more than the average of ordinary castings.

Large discrepancies in strength of bars may result from a blow-hole or cold shut in the fracture, or from a corner of a bar not having run full, in which case it is not necessary to include the result in making up the average. Generally, however, a study of the fracture under a lens will not reveal any reason for the low strength.

Chill.—The surfaces of the yokes that form the ends of the mold chill the ends of the test bars. The yokes do not affect the test bars, except at their ends. By breaking the end of a test bar lengthwise the depth of the chill can be measured. Lay the end of one of the broken square bars upon an anvil. Place the point of a cold chisel (Fig. 21) a little behind the chilled portion, and a blow from a hammer will split off a side of the bar. By the eye decide where the chill fairly stops, measure its distance from the end in hundredths of an inch, and record this as the chill of the iron. Iron for thin castings, like stove plate and light hardware, will have from $\frac{1}{16}$ to $\frac{3}{16}$ of an inch chill. In machinery castings containing less silicon the chill will run up to half an inch at times.

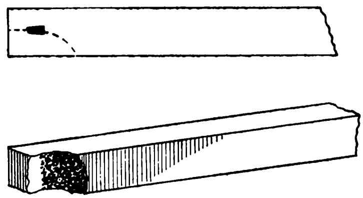


Fig. 21

Nos. 1 and 2 pig-iron often give bars with no chill.

Grain.—The character of the fracture is recorded as seen through a double convex lens, the two having together a focal distance of three-quarters of an inch, the diameter of the lens being 1¼ inches (Fig. 22). We have obtained better results from this combination than from any other lens.

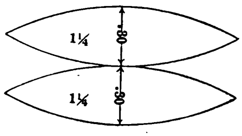


Fig. 22

What has now been described is the ordinary foundry test. It may seem too precise, but having started quite a number in the use of this test, we know how hard it is for a beginner to realize what serious errors creep in by making slight changes; also that the ordinary foundryman is not used to accurate methods.

We would advise that each one should become accustomed to what we have described before he attempts anything farther. Nothing more is needed for ordinary everyday practice. For testing mixtures of iron that are supposed to run regular, select one day each week, and have 4 pairs of bars poured from the center of the heat, ground, measured for size, shrinkage and chill, determine strength, and record all on one sheet of diagram paper, together with the mixture of the iron, unless a book is

kept for a record of mixture. Take a test also the day before a change is made in the mixture. This, with the hints given in the paper on "Silicon in Foundry Mixtures," and at the end of this paper, will enable a foundryman to do almost anything he wishes with his iron.

Fluidity.—Iron may be very thinly liquid, and may freeze quickly, or it may not be so fluid, but by remaining liquid longer will fill the mold better than the former.

It is a very difficult thing to measure fluidity, and it is a question whether we can measure it.

So far as we are aware, the method here described is as satisfactory as any. Use a pattern one foot long, one inch wide, and $\frac{8}{10}$ inches thick, and run it from the end (see the thin bar in Fig. 23). It is a rare thing for the bar to run its whole length.

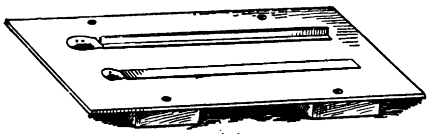


Fig. 23.

The length of the casting in inches is the measure of fluidity, and is no doubt a true measure for that particular cast, but the results are unsatisfactory if we try to find which of several mixtures of iron are the most fluid, as the heat of each at time of pouring will vary. In the study of grain and chill this strip may be of considerable value, it being so thin that by breaking it, the tendency to chill will be very apparent. The length that the fluid strip is gray, where chill begins, and where it be comes all white, are sometimes recorded.

Crook.—Along with the fluid strip, but poured by a separate gate, is another strip of the same dimensions as the fluid strip, but with a rib on one side (see Fig. 23). The distance that the rib has pulled the ends of the bar away from a straight line is the crook. To measure it an appliance is added to the measuring table. In the study of grain this strip brings out many peculiarities. In making these strips the greatest care must be taken to have the castings exactly like the pattern. We hardly recommend the use of either of these tests.

The Measure of Strength by Impact.—The effect of a dead load increased gradually until fracture takes place has been described. Metals are often used in places where they must resist shock.

The effect of a blow cannot be ascertained from the results of a test with a dead load. An iron may be able to sustain a great dead load, and yet break under a comparatively light blow, and *vice versa*. If you wish to know its resistance to impact, you must use a machine especially constructed for the purpose. Blows from a sledge repeated on a casting cannot be delivered at the same spot or with equal force, and in any case the break occurs on account of injury to the grain. The ordinary method of testing car wheels, by letting fall a weight in a sort of pile driver on the hub, may not injure the grain, and if so, is a satisfactory test for wheels.

Keep's Impact Testing Machine. —For testing the standard half-inch square bars by impact, where we cannot know how much of a blow the bar will bear, the center of the bar is protected so that the grain cannot be injured, and then blows are delivered with a 25-pound hammer, beginning with a fall of one-eighth of an inch, and one-eighth of an inch fall is added to each subsequent blow until fracture takes place.

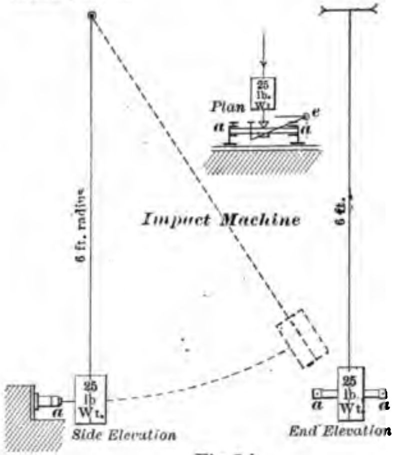


Fig. 24

No change in grain due to crystallization, can take place during the delivery of such a small number of blows, and reasoning from our experience with the dead load machine, probably each blow, short of the one that breaks, makes the bar a perfect spring for all blows less than that one, though this

Fig. 25.

is not exactly true, for the reason that the blows being so sudden, and the rebound being equally sudden, the grain does not have time to adjust itself to the deflection.

The deflection is, therefore, generally greater for the same bars when broken by impact than when broken by dead load. To insure accuracy the 25-pound hammer swings on a six-foot radius. Fig. 24 shows three outline views of this machine, while Fig. 25 is a perspective view.

The bed plate is not heavy enough to resist all blows, and it is better to set the forward end against a brick wall. The test bar is clamped in the same recording device, and the same pencil and paper are used as in the dead load machine. To the paper holder is attached a cord passing over a sheave, and a weight at the end tends to pull the paper holder along. On the rebound of the hammer a shuttle releases one of the pins on the paper holder, and allows it to move $\frac{3}{16}$ of an inch to carry the record of the previous blow out of the way, and to bring a clear place under the pencil to receive the next record.

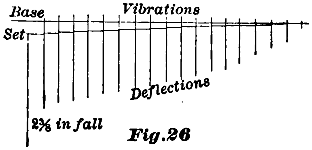


Fig. 26

Fig. 26 is a diagram made by this machine, and records deflection, set and vibration of the bar at each blow, A base line must be drawn, but it is as well or better to draw it after the diagram is complete, as it will always be parallel with the edge of the paper. The routine in making a test with this machine is very important.

See that the shuttle is in place to release the pins on the paper holder. See that there is a weight on both paper holder and shuttle to hurry their action. See that the pencil is sharp, with a very strong point, and that it is gripped tightly. The test bar lies with its number up, and on the end nearest you. See that the cage is wedged securely to the bar, and that the end set-screws are tight. The hammer should lie against the receiver. Set the catch at the hole of the one-eighth inch fall.

Draw back the hammer with the left hand, and catch it on the trigger. This backward movement has worked the shuttle, and has moved the paper, thereby marking the commencement of the base line. With the right hand press the trigger and release the hammer. As it swings forward and strikes a blow, with the right hand move the catch forward on the arc one hole, and with the left hand catch the hammer on its rebound, and bring it up to the trigger. Repeat these blows, increasing each by one-eighth of an inch fall; that is, move the trigger back one hole each time until the one-inch fall has been reached, at which time you must tighten the cage and set-screws. Make this examination after each stroke for even inches is reached, or oftener. Continue in this way until the bar breaks. Read from the arc the height of the fall which

broke the bar, and mark it on the diagram. A base line can now be drawn from the beginning already made, and parallel to the edge of the paper. From this line deflection, set and vibration can be measured. When both machines are used, six bars should be made to give an average of three for each machine.

Comparison of Results by Dead Load and Impact.—If test bars that will take set are used, and it is remembered that for all stresses less than the highest proof stress the bar is a perfect spring, a bar can be tested to a given stress on one machine, and then the recorder with test bar, may be transferred to the other machine, and stress applied until set begins, then transfer back again and make another diagram. In this way for a given material it may be found approximately what impact is equal to a given dead load. There is no uniformity of results with different sets of bars from different materials, and the indication is that

TABLE I.

Inches fall of 25-lb. hammer.	Inch-pounds developed.	Value of each blow in lbs. avoirdupois.	Inches fall of 25-lb. hammer.	Inch-pounds developed.	Value of each blow in lbs. avoirdupois.
.12	3.12	16.94	3.12	78.12	423.53
.25	6.25	33.88	3.25	81.25	440.47
.37	9.37	50.82	3.37	84.37	457.41
.50	12.55	67.76	3.50	87.55	474.35
.62	15.63	84.70	3.62	90.63	491.29
.75	18.70	101.65	3.75	93.70	508.24
.87	21.87	118.59	3.87	96.87	525.18
1.00	25.00	135.53	4.00	100.00	542.12
1.12	28.15	151.46	4.12	103.12	559.06
1.25	31.25	169.41	4.25	106.25	576.00
1.37	34.38	186.35	4.37	109.37	592.94
1.50	37.41	203.29	4.50	112.55	609.88
1.62	40.61	220.23	4.62	115.63	626.82
1.75	43.72	237.18	4.75	118.70	647.77
1.87	46.87	254.12	4.87	121.87	660.71
2.00	50.00	271.06	5.00	125.00	677.65
2.12	53.13	288.00	5.12	128.12	694.59
2.25	56.25	304.94	5.25	131.25	711.53
2.37	59.37	321.88	5.37	134.37	728.47
2.50	62.55	338.82	4.50	137.55	745.41
2.62	65.63	355.76	5.62	140.63	762.35
2.75	68.70	372.71	5.75	143.70	779.30
2.87	71.87	389.65	5.87	146.87	796.24
3.00	75.00	406.59	6.00	150.00	813.18

Fig. 27.

each set of bars has a dead load and impact result, dependent upon some peculiarity in the chemical or mechanical composition of such bars, and one cannot be correctly calculated from the other by any formula.

A blow is expressed in inch or foot-pounds (25 × by height of fall), but this cannot be compared with pounds avoirdupois. To be able to make

a comparison, some years ago we constructed table I., on page 21, (Fig. 27), which has been proved perfectly satisfactory where all results are relative.*

It must be observed that while the proportions of this impact machine were at first selected arbitrarily, yet it is now necessary to adhere to these proportions, to make the results comparable with those which have been obtained and have been published.

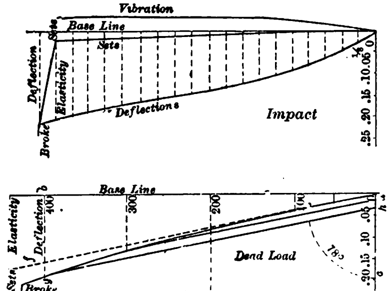


Fig.28

Examples of Diagrams.—To illustrate what these machines will reveal, some examples of diagrams, both dead load and impact, are produced from cast-iron in Fig. 28, and from a rolled ½-inch bar of wrought-iron (Fig. 29).

The full record of a test of pig-iron is given from our record book (Fig. 30).

Hardness.—Fig. 31 represents the machine used in "Keep's Test," which was invented by Professor Thomas Turner, Mason College, Birmingham, Eng., and to which we have added some improvements.

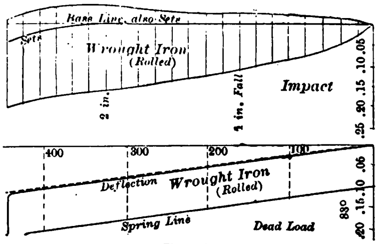


Fig.29

At the end of a perfectly balanced arm is fixed a standard diamond which bears upon the polished end of a test bar. By placing gram weights on the diamond until it makes a standard scratch on a standard polished surface, the number of grams on the diamond point is the number which represents the hardness of the metal. Results depend largely upon the skill of the operator, but are probably more reliable than results obtained by any other method.

The Testing of Pig-Iron.—Nothing can be more unsatisfactory than to melt a few hundred pounds of any one brand of pig-iron in a small cupola in contact with the large amount of fuel required, and such remelted iron is entirely unlike the average iron from a cupola after it

*Table 1 shows the number of inch-pounds developed by each blow. Also gives an arbitrary value to each blow in pounds avoirdupois, to allow comparison and tabulating with records from Keep's dead load machine.

The value for an inch-pound was obtained by testing a good sample of Swedish gray pig-iron which broke in the dead load machine with 288 pounds and by impact with a 2⅛-inch fall. The table was constructed from this data.

has become hot. A furnace should be constructed something like a brass furnace, about 30 inches deep and 13 inches square on the inside, with a fire-brick cover which can be easily removed. It must have a tight ash-

No. Test. 176	Brand Poughkeepsie No. 1.						Transverse Strength.			
No. Set	Size. h.	b.	Shrinkage. Cold ■ Hot.		Cold — Hot.		lbs Av.	Def.	SET.	
1	496^{2}	496^{2}	134	133^{2}	150	148^{2}	350	.25		D. LOAD
2	499	491	135	135	149	146	350	.25		D. LOAD
3	497	493	133^{2}	133^{2}	146	143	365	.24		D. LOAD
4	495^{2}	496	134	134	150	148^{2}	322			IMPACT.
5	495	494	133^{2}	133^{2}	149	146^{2}	339			IMPACT.
6	500	492	137	137	148	145^{2}	329			IMPACT.
Averages D. L.	497^{2}	493^{2}	134^{2}	134^{2}	148^{2}	146^{2}	355	.25		D. L.
Averages Imp.	497	494					333			IMP.
Crook	.022									
Fluid/10	.50									
Chill	.12									
Hard										

REMARKS.
Fluid Strip. Over gray part lead color. On edge of gray very yellow. As chill whitens yellow turns to white. On other side the edge of gray is crimson-brown, then gold, then blue & gold, then green, & at edge is purple. Fracture shows that chill begins on edge at $5\frac{1}{2}$ in. & all chilled at 10 inches.
Crook Strip very slight chill at the edge of the cold end.
Thin Bar no chill at all on the edges. A little blue stain near gates.
□ Cross Fracture. Very fine large mottle, dark preponderating & the white lines distinct but containing very small black grains, giving a dark appearance to the fracture to the naked eye. Longitudinal Fracture has finer mottle & very definitely marked, the white network being complete. Round black grains run into the chill. The Chill is white & smooth. Chemical Analysis of another pig from the same stock pile gave P. 1.242 S. trace. Si. 2.946. Mn. 0.189. G.C. 2.879 C.C. 0.464.

pit, and must be driven by a fan. The blast may be taken from the same pipe that supplies a forge near by, if the blast can be continuous for ten hours during the day. The pressure in the pit should be about 2½ ounces to give best results. Use the best Connellsville coke and use a No. 16 Dixon's crucible (brass). From five to fifteen pounds of iron will make a test, and the latter will make six or eight pairs of bars. If fifteen pounds of iron is put in in one piece it will melt in from twenty-five to forty minutes. It is well to cover the crucible with the bottom of an old one. If the furnace is to be run all day it is best to draw the grate bars and clean out the cinders and ashes at noon. Six or eight heats can be made in a day, and a crucible will stand forty heats or more.

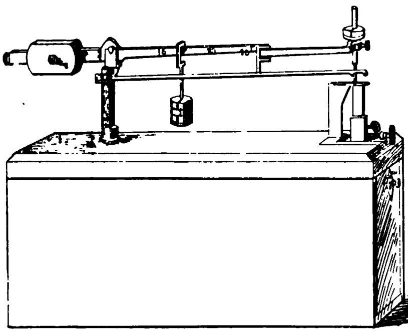


Fig. 31

Enough sand for the whole day's work should be tempered the night before, so as never to use the hot or dried sand. Fig. 6 shows a molder at work, and Fig. 32 shows our furnace and the manner of pouring from

the crucible in our testing room.* A good chimney flue must be connected with furnace just under the cover. The work is so severe that both furnace and chimney must be securely clamped. The furnace lining will seldom last more than four or five days if used continuously. The flame comes out of all cracks, therefore no free oxygen can enter the crucible, and the cover prevents a circulation of gases in the pot.

Fig. 32.

At best there is considerable variation in duplicate casts from the same iron, but generally the test bars do not materially vary from the pig-iron. If you are mixing several brands of pig-iron in a cupola, and the results are not satisfactory, a test of each brand will generally show which iron is causing the trouble and which iron is the best

Foundry Practice with Keep's Test.—No iron producers can deny the results of such a test. It is well to stipulate when purchasing pig-ron for thin castings that it shall have no chill when melted in this way. If it were possible by chemical analysis to determine what change should be made in a mixture of iron to produce a desired result, such a course is expensive and slow. Cheap irons cannot be purchased on guaranteed analysis, for a furnace will not run regularly, and even the

*When convenient we would advise making the top of the furnace even with the floor, like a furnace in a brass shop.

two ends of the same pig will not give the same analysis. In ordinary marketable pig-iron, phosphorus and manganese will not run over one per cent., and sulphur will run only a few hundredths. As the first two exert very little influence on foundry iron, and do not increase chill or make iron white, we may ignore their presence. It is well to purchase irons that have a good reputation. The most common element found in pig-iron and the most important is silicon. Its presence up to about three per cent. makes iron soft and gray and reduces shrinkage.

It does this by changing carbon into dark and bulky graphite, which colors the iron and makes the casting larger. Silicon is an antidote for anything that produces an opposite effect. All we have to do therefore in every day practice is to see that silicon is present to the extent that is required.

Owing to circumstances, the founder must purchase the iron that is cheapest in the market, and from it make the best castings. Iron that is low in silicon is cheap, and *vice versa.* We should therefore get as much silicon as possible in cheap irons. Often close-grained, light-colored No. 2 or 3 pig is higher in silicon than a more open and darker iron. For large castings silicon must be low, and for thin castings it must be higher.

If chilled castings are to be made, irons must be selected that have a natural tendency to chill. Such tendency is not due to ascertained chemical composition. If a foundry applies "Keep's Test" to a casting which is acceptable, its shrinkage, chill and strength is a standard by which to judge future work. Within certain limits, by keeping the shrinkage uniform, the castings will be uniform. As a practical application we will first present the record of tests of four brands of pig-iron, and then present the results of four mixtures of these four irons.

The grain of the fracture of the center of a test bar is shown by the square drawings, while the rectangular drawings represent a part of a bar with the side broken off, showing the depth of chill and the grain.

The chemical analysis of test bars of the pig-irons is given in table II.

TABLE II.

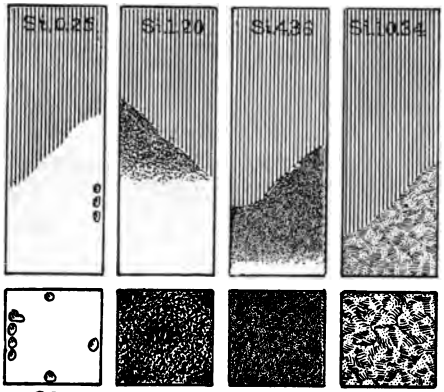
No. Test		T. C.	Si.	P.	Mn.	S.	G. C.	C. C.
376	White Pig Iron......	3.13	0.25	0.26	0.09	0.03	1.62	1.51
441	Gray Pig Iron...	3.55	1.20	0.84	0.18	0.04	3.22	0.33
397	Gray Silicon Pig.....	....	4.36	....	....	....	....	...
401	Flaky Silicon Pig....	1.99	10.34	0.45	0.52	tr.	1.92	0.07

The figures on the ends of the test bars indicate the actual chemical analysis of those bars. It was intended to have them as nearly as possible 1.50, 2.00, 2.50 and 3.00 per cent.

The original pig-iron from which 376 was made contained T. C. 2.98, of which only 0.95 was G. C. 397 is supposed to be of nearly the same composition as 401 except as to silicon.

TABLE III.

No. Test.	Iron.	Dead Load.		Impact.		Shrinkage.		Hardness.	Chill.	D. L. Strongest Single Test Bar.
		Strength.	Def.	Strength.	Def.	Sq. Bar.	Thin Bar.			
376	White....	379	.14	237	.16	.248	.246	100	All.	384
441	Gray.....	362	.27	339	.29	.168	.186	74	.40	379
397	Silvery...	478	.25	425	.27	.139	.146	64	.10	514
401	Flaky	231	.12	125	.11	.199	.201	132	.0	245



376 441 397 401

FIG. 33

Fig. 33—(table III) shows the four original irons.

The following records show the results of adding to one of the two pig-irons, enough of one of the silicon irons to make test bars with 1½, 2, 2½ and 3 per cent. of silicon (actual analysis is marked on the bars). They show that the peculiarities of a pig-iron remain in the mixture, and will not be wholly eliminated by a change of chemical composition.

Fig 34—(table IV) is a mixture of white pig-iron (376) and a portion of flaky silvery iron (401.)

TABLE IV.

No. Test.	Percentage. Silicon.	Dead Load.		Impact.		Shrinkage.		Hardness.	Chill.	Strongest Bar.
		Str'n.	Def.	Str'n.	Def.	Sq. Bar.	Thin Bar.			
344	1½ per cent. silicon.	466	.14	299	.15	.227	.243	84	All.	495
345	2 per cent. silicon.	486	.21	356	.21	1.169	.339	60	1.25	508
346	2½ per cent. silicon	416	.19	362	.21	.163	.220	57	.60	432
347	3 per cent. silicon.	421	.23	451	.27	.155	.167	55	.22	469

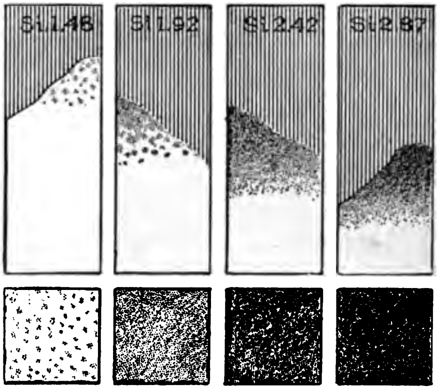
The carbon in the white pig-iron being nearly all in the combined state, so little of 401 was used that it introduced but little of its peculiar characteristics. The introduction of silicon has formed graphite artificially, making a very fine mottled grain and a very solid casting.

Fig. 35 (table V) is a mixture of the same white pig-iron (376) with gray silvery iron (397), which latter is made from a mixture of the same ores as 401, together with ores that alone would have made a high chilling iron. 397 would therefore carry a large per centage of silicon, and

still make a very close black iron much like the mixture in Fig. 34 if the silicon had been carried to 4½ per cent.

By using a low silicon softener we were obliged to use more of it, and have therefore imparted some of its other peculiar qualities.

The silicon is more effective than in Fig. 34, it taking one-half of one per cent. less silicon than in the former case to produce a given result. The extraordinary strength of the single bars of this mixture indicates what may be done by careful selection and mixing in foundry practice. The mixtures in Figs. 34 and 35 are what would be desirable for machinery castings and indicate the use of low grade pig-iron low carbon and low silicon softeners. No. 1 pig-iron is a softener, with silicon about 3 per cent; it is therefore necessary to use more of it.

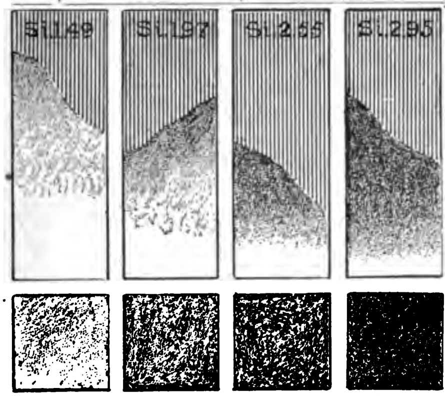


344 345 346 347

FIG 34

TABLE V.

No. Test.	Percentage. Silicon.	Dead Load.		Impact.		Shrinkage.		Hardness.	Chill.	Strongest Bar.
		Str'n.	Def.	Str'n.	Def.	Sq. Bar.	Thin Bar.			
340	1½ per cent. silicon..	501	.19	486	.27	.179	.243	65	1.25	540
341	2 per cent. silicon..	464	.22	390	.20	.161	.217	57	.60	475
342	2½ per cent. silicon..	498	.27	466	.29	.156	.161	56	.20	505
343	3 per cent. silicon..	452	.25	390	.22	.147	.160	53	.18	460



340 341 342 343

FIG 35

While testing samples we found one white pig-iron with silicon 1.97 and shrinkage square bar .241, thin bar .235, dead load strength 566, deflection 19, impact 412, hardness 65, strongest bar 596, def. 20. On the other

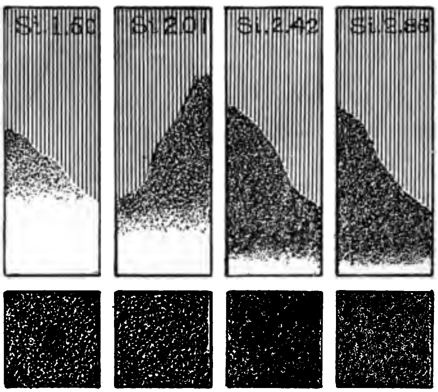
hand, we have found a white casting of substantially the same chemical composition with silicon 2.74 that was very tender.

It is a very rare thing for iron to be high in silicon and still remain white.

TABLE VI.

No. Test.	Percentage. Silicon.	Dead Load.		Impact.		Shrinkage.		Hard-ness.	Chill.	Strong-est Bar.
		Str'n.	Def.	Str'n.	Def.	Sq. Bar.	Thin Bar.			
348	1½ per cent silicon.	362	.23	345	.25	.162	.175	58	.40	375
349	2 per cent silicon...	363	.23	334	.22	.156	.158	45	.22	365
350	2½ per cent silicon.	380	.28	350	.28	.143	.149	42	.10	390
351	3 per cent silicon...	370	.26	385	.27	.134	.153	28	.08	380

Fig. 36 (table VI) is a mixture of the gray pig-iron (441) with the low silicon pig (397), both having some tendency to chill.



348 349 350 351
FIG.36

Fig. 37 (table VII) is a mixture of the gray pig-iron (441) with the high silicon softener (401) which latter has no chilling tendency.

Graphitic carbon is a weakening element, especially if the grain be coarse. We see that if we wish little chill and low shrinkage we must use pig-irons with low chill, and that shrinkages may be lowered by mixture more than can be accounted for by that of the original irons.

If softness, lack of chill and low shrinkage are of more account than great strength, gray irons will be selected. While silicon will control the whiteness yet some irons will carry more silicon than others. In our foundry the bulk of the castings are very thin,

TABLE VI.

No. Test.	Percentage. Silicon.	Dead Load.		Impact.		Shrinkage.		Hard-ness.	Chill.	Strong-est Bar.
		Str'n.	Def.	Str'n.	Def.	Sq. Bar.	Thin Bar.			
352	1½ per cent silicon.	365	.23	373	.29	.163	.181	54	.40	380
353	2 per cent silicon..	348	.23	228	.23	.161	.162	50	.20	360
354	2½ per cent silicon.	318	.24	277	.24	.141	.149	39	.07	380
355	3 per cent silicon...	348	.30	401	.32	.148	.148	42	.08	355